INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue III, March 2025

IOT-Based Real-Time Air Quality Monitoring System Using ESP8266

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DOI : https://doi.org/10.51583/IJLTEMAS.2025.140300019

Received: 17 March 2025; Accepted: 24 March 2025; Published: 03 April 2025

Abstract: In today's world, one of the growing concerns is Air Pollution, due to its adverse impact on human health and environmental quality. This research paper presents the design and implementation of a Real-Time Air Quality Monitoring System measuring the Air Quality Index (AQI) using sensors such as MQ135, PM2.5, and DHT11. The ESP8266 microcontroller is used to collect and analyze data. The system is built to provide local display via LCD and remote display through a web dashboard interface. The system has buzzer alerts for local alert generation when AQI thresholds are crossed, and alert messages are generated simultaneously in the web interface. The system uses the HTTP protocol for communication and let the users download CSV files to access the previous air quality data history. The proposed model aims to develop a low-cost, real-time sensing Air Quality Monitor using widely available microcontrollers and sensors to bring awareness to every individual about the harmful living environment.

Index Terms—Air Pollution, Air Quality Index (AQI), Sensors, Microcontroller, HTTP, CSV, ESP32

I. Introduction

When harmful substances including particulates and bio- logical molecules are introduced into the Earth's atmosphere, it leads to Air Pollution. It may cause diseases and allergies which adversely affect human health, leading to respiratory diseases such as cardio-vascular problems and other long-term complications. It is harmful to other living organisms as well and it also affects food crops and damages the environment. Human activities such as smoking, and the use of cleaning agents in the home containing harmful chemicals and dust leads to air pollution. Therefore, monitoring air quality is not just a necessity for regulatory compliance, but a vital measure to protect health and promote sustainable living.

Traditional air quality monitoring is mainly large, expensive and stationary systems that are used by governments or specialized institutions. However, these systems are not easily accessible to the public, and they often lack real-time feedback

*All authors have equal contribution. for localized environments such as homes, offices, or small communities. To address these limitations, this report focuses on developing a low-cost, compact and real-time air quality monitoring system using IoT technology (Internet of Things). This proposed system uses a wireless network of low-cost sensors and hardware components along with the necessary software to effectively monitor the quality of air in a confined close space.

The quality of air is captured using various sensors that are integrated into the system. The MQ135 sensor detects harmful gases such as ammonia, nitrogen oxide, alcohol, and smoke that contribute to poor air quality. Particulate matter, which is among the most dangerous pollutants due to its ability to penetrate the lungs, is measured using PM2.5 sensors. In addition, temperature and humidity levels are monitored using DHT11 sensors. These sensors provide crucial data about the components of air which significantly influence the dispersion and impact of pollutants. The ESP8266 microcontroller is used as the heart of the system. It processes the sensor data and hosts the web server for the dashboard interface. The outcome of the processed data is the Air Quality Index (AQI) value, which is a standard metric to measure air quality levels.

When air quality reaches dangerous levels, the buzzer provides an immediate auditory alert for users when AQI thresholds are crossed, while a JHD 162A LCDs real-time data locally. The system includes a web dashboard built with HTML, CSS, and JavaScript to extend usability and accessibil- ity. This dashboard fetches real-time data from the ESP8266 over HTTP and displays it. When air quality thresholds are crossed, users can view live AQI, temperature, and humidity readings and receive alerts.

The system is designed to provide actionable information on air quality for localized environments such as homes, offices, or small communities. In addition, it seeks to cre- ate an efficient and user-friendly solution by leveraging IoT technology to deliver real-time feedback, empowering users

to make informed decisions about their environment. It also highlights the potential of IoT technology in solving real-world problems, paving the way for more advanced and personalized environmental monitoring solutions in the future.

Related Work

Several studies have explored IoT-based air quality monitor- ing. Hossain et al. [1] developed a low-cost IoT device using ESP8266 and Atmega328 for real-time air quality monitoring, providing local alerts but lacking advanced web-based visu- alization. Sahoo et al. [2] proposed an industrial air quality monitoring system using IoT, integrating multiple sensors but

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requiring extensive cloud-based data processing. Kayes et al. [3] designed a platform incorporating ESP32 with real- time AQI calculations and web dashboard integration. Our proposed system improves upon these by integrating real- time data visualization, web-based alerts, and optimized sensor calibration which enhances the system accuracy and response time. thresholds, different actions are taken. If AQI is below 50, the green LED is activated, indicating safe air quality. If AQI falls between 50 and 100, the system triggers a blue LED as a ventilation alert. When AQI exceeds 100, the system generates an alert, activates a buzzer, and turns on the red LED to indicate hazardous conditions. The alert remains active until acknowledged, ensuring prompt user intervention. This automated response mechanism improves the assessment of air quality and promotes timely corrective measures.

System Overview

Block Diagram of the System

Fig. 1 shows the block diagram of the proposed system. The hardware consists of an ESP8266 microcontroller, which collects real-time environmental data from multiple sensors, including temperature, humidity, dust concentration, and gas levels. The DHT11 sensor measures temperature and humidity, while the MQ135 (gas sensor) and PM2.5 (dust sensor) detect air quality and particulate matter levels. To achieve real-time monitoring, data is displayed on a LCD screen, and for remote access, the ESP8266 transmits sensor data to a web-based dashboard that provides live updates, analytics, and threshold alerts.

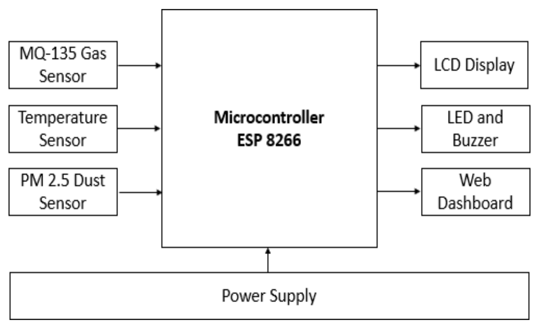

Fig. 1. Overview of the proposed air quality monitoring system.

Flow of Control

Fig.2 depicts the flowchart which illustrates the decision- making process of the air quality monitoring system. The system begins by collecting real-time sensor data from various environmental sensors. The collected input is transmitted to the ESP module, where it is processed to compute the equivalent value of the Air Quality Index (AQI), based on predefined

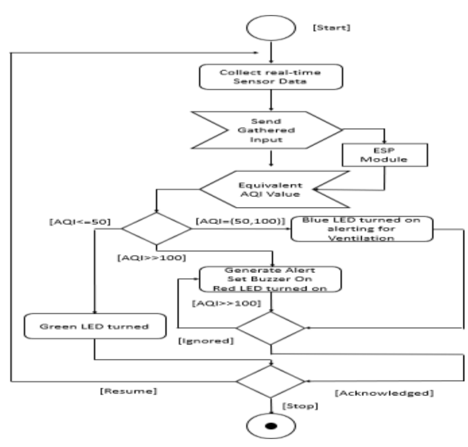

Fig. 2. Flowchart of the system.

II. Methodology

Data Acquisition

The data is continuously collected by the system from multiple sensors to monitor environmental conditions and air quality in real time.

1) MQ135 Gas Sensor: The concentration of smoke, harm- ful gases such as ammonia, nitrogen oxides are measured by this sensor. The output of this sensor is analog signals proportional to the intensity of detected pollutants, providing essential data for air quality analysis.

2) PM2.5 Sensor: The fine particulate matter, focusing on particles smaller than 2.5 microns, is detected by PM2.5 sensors.

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Digital output ensures precise monitoring, which is a critical component in evaluating pollution levels.

3) *DHT11 Sensor:* The temperature and humidity levels recorded by DHT11 are sent as a digital signal to the ESP8266 microcontroller. This information helps to contextualize air quality trends with environmental conditions.

4) *Real-time data update:* The data is updated every two seconds for continuous and real-time monitoring of environ- mental changes.

The integration of multiple sensors with the ESP8266 en- ables efficient data processing, ensuring that all parameters are accurately recorded and analyzed. These sensors work together to give a detailed view of air quality, helping users understand their environment with actionable insights in real time. With continuous data updates, the system ensures accurate and reliable monitoring.

Data Processing

After gathering data, the ESP8266 analyzes it to extract meaningful information, including the calculation of the Air Quality Index (AQI) value for an accurate assessment of air quality.

Threshold Declaration

The AQI values are compared by the system against prede- fined thresholds to categorize the quality of air into ”Good”, ”Moderate”, ”Poor”, and ”Hazardous”. Trigger alerts and web dashboard updates are based on the above classification, which ensure that users receive actionable insights. Based on general air quality guidelines and environmental standards, predefined threshold values are selected. These threshold values act as reference points to determine safe and harmful levels of environmental conditions:

5) *Temperature Threshold (26.0°C):* The temperature threshold is set to 26.0°C, which is derived from comfort levels used in home or office environments. When temperature exceeds the given limit, it results into affecting both air quality and personal well-being.

6) *Humidity Threshold (70%):* Based on general recom- mendations for indoor environments, the optimal percentage for humidity is 70% or less. High humidity levels (above 70%) are often associated with discomfort and can increase the risk of mold growth and other environmental issues.

7) *MQ135 Gas Sensor Threshold (100):* The MQ135 gas sensor is set at a threshold value of 100, following general air quality standards for gases such as ammonia, nitrogen oxides, and carbon dioxide. When this level is exceeded, it indicates rise in pollution and a decline in overall air quality.

8) *PM2.5 Sensor Threshold (500):* The 500 threshold for PM2.5 levels is set on the basis of air quality standards es- tablished by environmental health organizations. Levels above this threshold indicate dangerous air quality due to high concentrations of fine particulate matter, which can lead to significant health risks.

These thresholds help to determine whether the air quality is within acceptable limits and allow the system to trigger alerts when certain environmental conditions are exceeded.

Overall AQI Calculation

The final AQI value is calculated by combining the individ- ual components of the air. The PM2.5 data is given a weight of 60%, the MQ135 data is weighted at 30%, and the DHT11 data is given a smaller weight of 10%. This weighted sum is used to calculate the final AQI value, which is used to classify the quality of air as Good, Moderate, Poor, or Hazardous.

$$AQI = (0.6 \times pm25AQI) + (0.3 \times mq135AQI) + (0.1 \times dht11AQI)$$

Data Transmission and Visualization

The processed AQI data is displayed both locally and remotely.

9) *Local LCD Display:* The JHD 162A LCD presents real- time readings for on-site monitoring.

10) *Web Dashboard:* The ESP8266 transmits data to a web- based interface via HTTP requests. The dashboard, built using HTML, CSS, and JavaScript, dynamically updates air quality readings every 2 seconds.

11) *Alert Mechanism:* The system triggers a buzzer and flashes LED alerts when AQI level crosses hazardous thresh- olds. Data Reference Index:

12) *Good Air Quality ($AQI \leq 50$):* When the AQI level is 50 or below, the system considers the air quality to be good. In this case, the green LED is turned on to visually indicate that the air quality is safe.

13) *Moderate Air Quality ($50 < AQI \leq 100$):* If the AQI level is between 51 and 100, indicating moderate air quality, the blue LED is activated. This provides a visual cue that air quality is acceptable but could be improved.

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14) Poor Air Quality (AQI > 100): When the AQI level exceeds 100, the air quality is considered poor, and the red LED is turned on. This alerts the user that air quality is harmful and should be addressed.

Additionally, if the AQI level exceeds 150, the air quality is considered "very poor" and the buzzer is activated. This provides an audible alert, which is especially useful in remote environments where visual cues may not be sufficient.

15) System Implementation and Testing: The system is de- ployed in a real-world environment to evaluate its perfor- mance. Sensor readings are compared with reference data from standard air quality monitoring stations to validate accuracy. Multiple test cases are conducted under different environmen- tal conditions to assess system responsiveness, data reliability, and wireless communication stability.

III. Result

The Air Quality Monitoring System successfully integrates multiple sensors to monitor and assess environmental condi- tions in real-time. Throughout the project, the performance of the system was evaluated across several key parameters, including air quality, temperature, humidity, and particulate matter, with outputs displayed on both hardware (LCD) and software (web interface). To validate the system, sensor read- ings were compared with reference AQI data from a standard monitoring station.

Test Condition	Govt. AQI	System AQI	Error (%)
Indoor(Low Pollution)	35	37	5.7%
Outdoor(Moderate Pollution)	90	92	2.2%
Traffic Area(High Pollution)	180	175	-2.8%

Real-Time Monitoring

The system efficiently collects and processes data from the MQ135 gas sensor, PM2.5 dust sensor and DHT11 temper- ature and humidity sensor. Continuous data refresh ensures that readings are updated every two seconds, allowing real- time tracking of environmental conditions. By integrating these sensors with the ESP8266 microcontroller, seamless data acquisition was achieved, which is crucial for accurate air quality analysis.

AQI Calculation

The system successfully computes the Air Quality Index (AQI) by aggregating data from multiple sensors. Using pre- defined thresholds, the AQI categorizes air quality into Good, Moderate, Poor, or Hazardous levels, providing users with a clear and intuitive understanding of environmental condi- tions. In addition, a discomfort factor based on temperature and humidity is considered which further contextualizes the AQI value, ensuring a more comprehensive assessment of air quality.

Alert System

An effective warning mechanism is implemented using color-coded LEDs and a buzzer to notify users of air quality conditions. When AQI value crosses specific thresholds, the system triggers visual (LED) and audible (buzzer) alerts, ensuring immediate awareness of deteriorating air quality. This real-time feedback enhances safety and allows users to take necessary precautions.

Web Interface

A user-friendly web dashboard enables remote monitoring of air quality data in real time. The dashboard dynamically updates every two seconds, ensuring that users receive the latest sensor readings. Additional functionalities include data export in CSV format, allowing users to store and analyze historical air quality data. The interface also features a memory reset function, which ensures long-term system efficiency by clearing unnecessary stored data.

Data Storage and Retrieval

The system efficiently logs sensor readings along with timestamps, storing them in CSV format for easy retrieval and analysis. The ability to download recorded data via the web interface enhances the user experience, enabling further evaluation of air quality trends and patterns.

Calibration and Accuracy

Calibration played a critical role in ensuring accurate sensor readings. Threshold values were carefully chosen based on standard air quality guidelines, allowing the system to cor- rectly classify air quality levels and trigger alerts as required. This calibration process, combined with the precise sensor data, ensured that the system met the accuracy standards necessary for reliable air quality monitoring.

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IV. Conclusion

This paper presents an IoT-based air quality monitoring system using ESP8266 and real-time web visualization. The system achieved an AQI calculation accuracy of ±2.5%, with a response time of 2 seconds. Compared to existing solutions, our approach enhances efficient monitoring while maintaining affordability. Future work includes cloud-based data analytics, AI-driven analysis of past trend, and expanded sensor integration for NO_2 and CO levels

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